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Article

Palynological record of the Silurian/Devonian boundary in the Argentine Precordillera, western Gondwana

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With 10 figures

Abstract: The palynological assemblages of the upper part of the Los Espejos Formation and the lower part of the Talacasto Formation, in the northern outcrops of San Juan Precordillera, Argentina, were studied. This section spans the Silurian/Devonian boundary. Therefore the palynological analysis helps to constrain the age and to identify the position of the system boundary. This age interval has been much discussed owing to the scarcity of stratigraphically valuable fossils. The miospores and marine phytoplankton present in the upper part of the Los Espejos Formation, point to a Late Ludlow/ Přídolí? to early Lochkovian age. The occurrence of relevant biostratigraphic species such as *Dictyotriletes* cf. *emsiensis* Morphon, *Cymbosporits proteus*, *Amicospopites streeli* and the possible presence of *Streelispora newportensis*, permit the identification of the Silurian/Devonian boundary within the Los Espejos Formation. This system boundary is recorded for the first time in the Precordillera based on palynological assemblages. The position of this limit coincides with that established based on faunal data. A Lochkovian age is also confirmed in the lower part of the overlaying Talacasto Formation in the studied section, thus supporting previous palynological and fauna data.

Key words: miospores, palaeophytoplankton, Precordillera of Argentina, Silurian/Devonian boundary.

1. Introduction

The stratotype of the Silurian/Devonian boundary has been identified in the Czech Republic by isotope studies and fossil groups such as conodonts, tentaculites and chitinozoans among others. (e.g., Paris et al. 1981; Fatka 1999; Chlupáč 1999 and references therein, Frýda et al. 2002). As regards the phytoplankton groups, like chlorophytes and acritarchs, relatively few and geographically limited publications have been carried out in reference to this limit and, in general, the recorded palynological assemblages are badly preserved and poor in abundance and diversity (e.g., Le Hérissé et al. 1997a; Brocke et al. 2006; Molyneux et al. 2013). During the Late Silurian and Early Devonian, the proliferation of land plants took place. Their decay products enhanced nutrient supply to the ocean (Bambach 1993; Gröcke et al. 1999; Porębska et al. 2004, but see also Tappan 1986) causing important environmental changes. Le Hérissé (2002) suggested that marine phytoplankton was extremely sensitive to variations in salinity, temperature, nutrient availability and climatic modifications, rather than to bathymetric changes.

Rubinstein et al. (2008), in their contribution about acritarch and clorophyte assemblages from the Early Devonian of the Solimoes Basin, Brazil, made an exhaustive review of worldwide Lochkovian organic-walled phytoplankton. They emphasized the presence of taxa, such as *Demorhethium lappaceum* Loeblich & Wicander 1974 and *Thysanoprobolus polykion* Loeblich & Tappan 1972, that have a widespread

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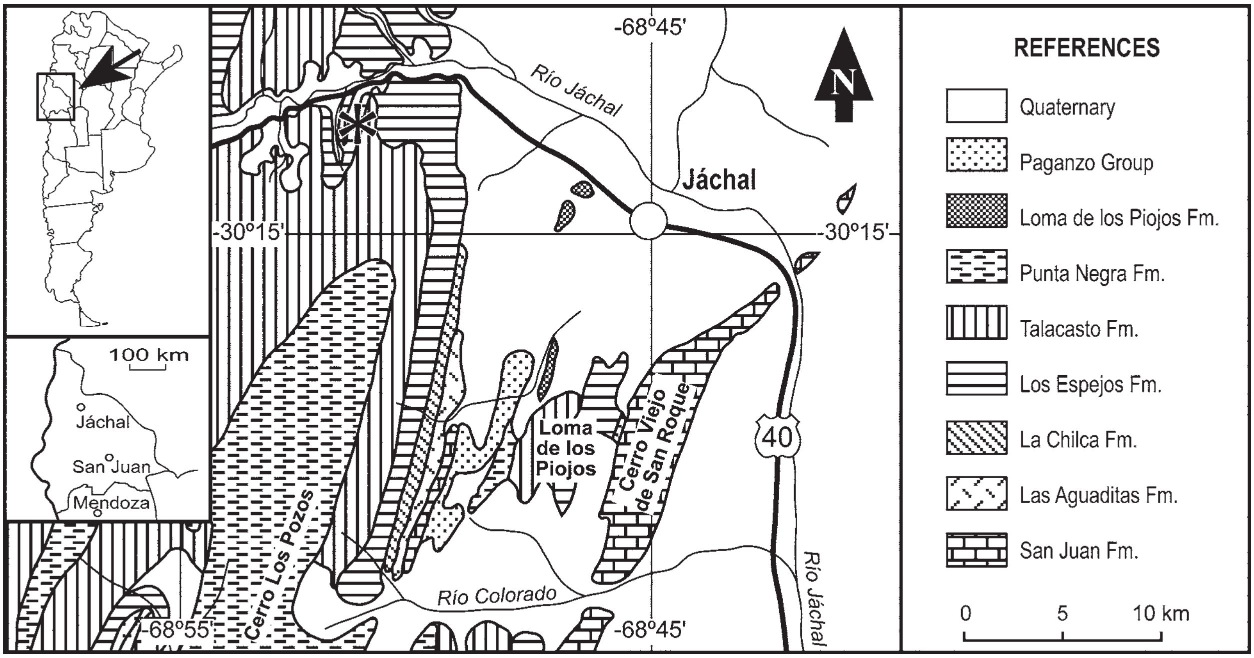

Fig. 1. Geologic and geographic map of the northern outcrops of the studied formations. The asterisk represents the studied area. Modified from Baldis (1975), Ferrero (2006) and Rustán (2011).

geographical distribution and are stratigraphically restricted (early Lochkovian), therefore making them usable for worldwide stratigraphic correlations. The genus *Schizocystia* is among the microphytoplankton taxa considered as markers for the beginning of the Devonian in Gondwana. However, in the Amazonas Basin (Urubu) *Schizocystia* first appears in Late Ludlow strata independently dated by chitinozoans (Steemans et al. 2008).

As regards the terrestrial palynomorphs, there are several publications about their usefulness as biostratigraphic markers of the Silurian/Devonian boundary in Laurentia (e.g., Richardson & McGregor 1986; Richardson & Edwards 1989), Peri-Gondwanan terranes (e.g., Richardson et al. 2001), and Gondwana (e.g., Loboziak et al. 1992; Rubinstein & Steemans 2002; Hassan Kermandji 2007). So far, the biozones described by Richardson et al. (2001) in Spain, are fairly comparable to the assemblages found in the Precordillera, since it is possible to identify the spore biozones LP (*Synorisporites libycus-?Lophozonotriletes poecilomorphus*), RS (*Chelinospora reticulata-Chelinospora sanpetrensis*) and the H (*Chelinospora hemiesferica*) sub-biozone. These biozones indicated a Ludlow-early Přídolí age for the Los Espejos Formation (García Muro et al. 2014). Furthermore, the TS biozone (*Synorisporites tripapillatus-Apiculiretusispora spicula*) defined by Richardson & McGregor (1986) for the Old Red Sandstone is recognized (García Muro et al. 2014), thus indicating a Přídolí-early Lochkovian age. The first Devonian miospore biozone, *micrornatus-newportensis* (MN) of Richardson & McGregor (1986), is recognized by the appearance of its index species *Streelispora newportensis* and, later, *Emphanisporites micrornatus*. These taxa indicate an early (but not earliest) Lochkovian age in, e.g. Laurentia, Avalonia, and the Moesian Terrane (Richardson & McGregor 1986 and references therein; Richardson et al. 2001; Steemans & Lakova 2004).

The first biostratigraphic studies of the Los Espejos Formation in the Precordillera of San Juan, Argentina, were carried on by Cuerda (1969a), based on the graptolite fauna. The author assigned this stratigraphic unit a Wenlock?-Ludlow age in the Cerro La Chilca and the Loma de los Piojos sections. Pöthe de Baldis (1975) was the first to record palynological assemblages from the Los Espejos Formation. She suggested a probable Wenlock-Ludlow? age. Rubinstein (1989) described

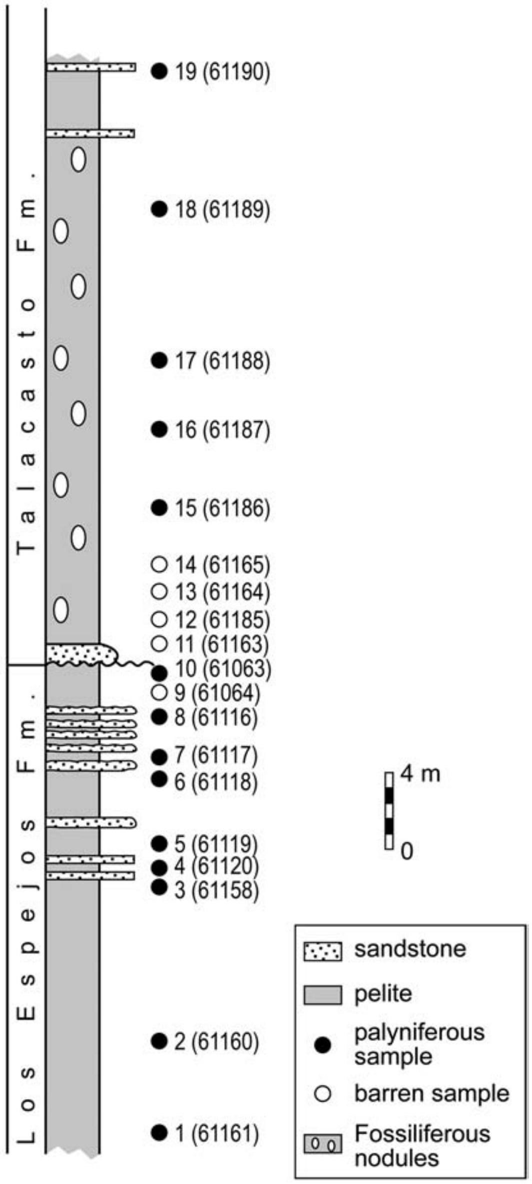

Fig. 2. Stratigraphic section of the studied Los Espejos and Talacasto formations in the Río Jáchal area. Circles and numbers indicate the studied levels.

a Late Silurian phytoplankton assemblage from near the Río Jáchal locality, similar to the assemblages described by Cramer (1964a) in different outcrops of the La Vid and San Pedro formations in Spain, dated as Ludlow-Early Devonian. Richardson et al. (2001) reanalysed the miospore and chitinozoan assemblages studied by Cramer (e.g., Cramer 1964a, b, 1966a, b, 1967, 1970); Cramer & Diez (e.g., 1968, 1975, 1978a, b, 1979) and Rodriguez (1978a, b) in order to pinpoint the age of the stratigraphic units. Thus, the ages formerly proposed by Cramer were modified, leaving the phytoplankton species still to be re-evaluated. The only Early Devonian palynological assemblage previously recorded in the Precordillera, corresponds to the lower part of the Talacasto Formation, in the Cerro del Fuerte locality, which overlies the Los Espejos Formation (Rubinstein et al. 1996; Le Hérissé et al. 1997b).

Benedetto et al. (1992) published a detailed biostratigraphic analysis of the Los Espejos Formation. Through the brachiopod assemblage they recognized, for the first time, the Silurian/Devonian boundary in the upper part of the Los Espejos Formation in the Cerro del Fuerte locality, which is the northernmost studied outcrop. These authors identified *Coelospira extensa* Benedetto & Toro 1987 which indicates a Přídolí age, followed by *Molongella* and *Australocoelia* genus, only known since the Lochkovian. Mollusc assemblages from the same locality support the presence of the Silurian/Devonian boundary within the Los Espejos Formation (Sánchez et al. 1995).

The aim of this paper is to report the miospore and phytoplankton assemblages recorded in the upper part of the Los Espejos Formation and the lower part of the Talacasto Formation, thereby proposing the probable position of the Silurian/Devonian boundary within the Los Espejos Formation, which so far has been uncertain in the Precordillera of San Juan.

2. Geological setting

The active margin of western Gondwana was affected by the Cuyania accretion during the Mid-Late Ordovician (Benedetto 2010). This collision produced the Talacasto-Tambolar arch in the Precordillera of San Juan, which affected the deposits of the Silurian- Devonian basin. The stratigraphic units wedge towards this arch, and important interruptions of sedimentation took place (Astini et al. 1995).

The Silurian and Devonian deposits of the Central Precordillera are represented by the Tucunuco Group (Cuerda 1969b), comprising the La Chilca (Cuerda 1965) and the Los Espejos (Cuerda 1965) formations and the Gualilán Group (Baldis 1975) consisting of the Talacasto (Padula et al. 1967) and the Punta Negra (Bracaccini 1949) formations. The boundary between both units has been interpreted as a paraconformity (Astini & Maretto 1996), where the hiatus probably involves part of the late Ludlow, Přídolí and early Loch-

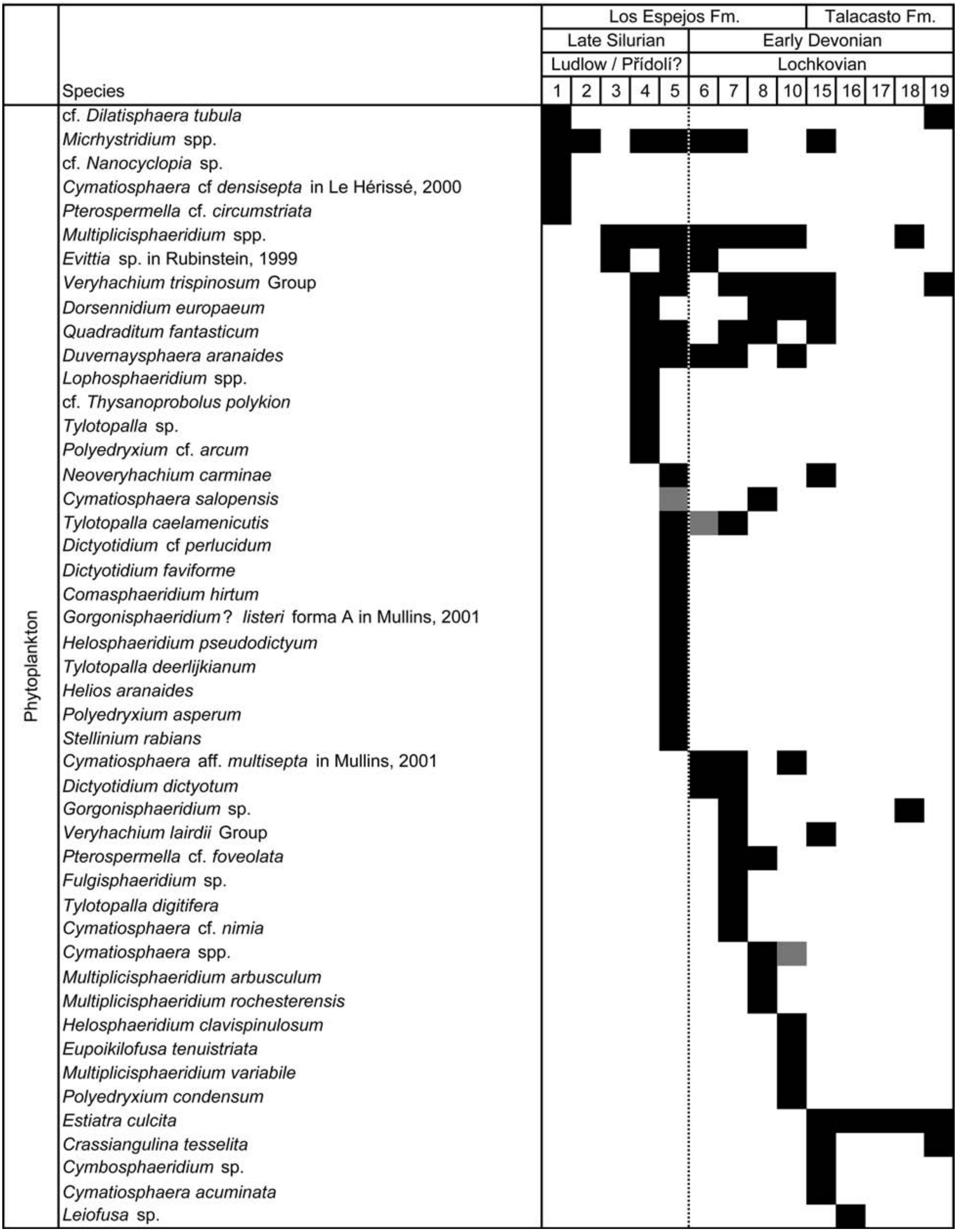

Fig. 3. Stratigraphic distribution of the phytoplankton species in the studied section and the proposed ages. Black rectangles mean presence of the species, grey rectangles mean doubtful classification.

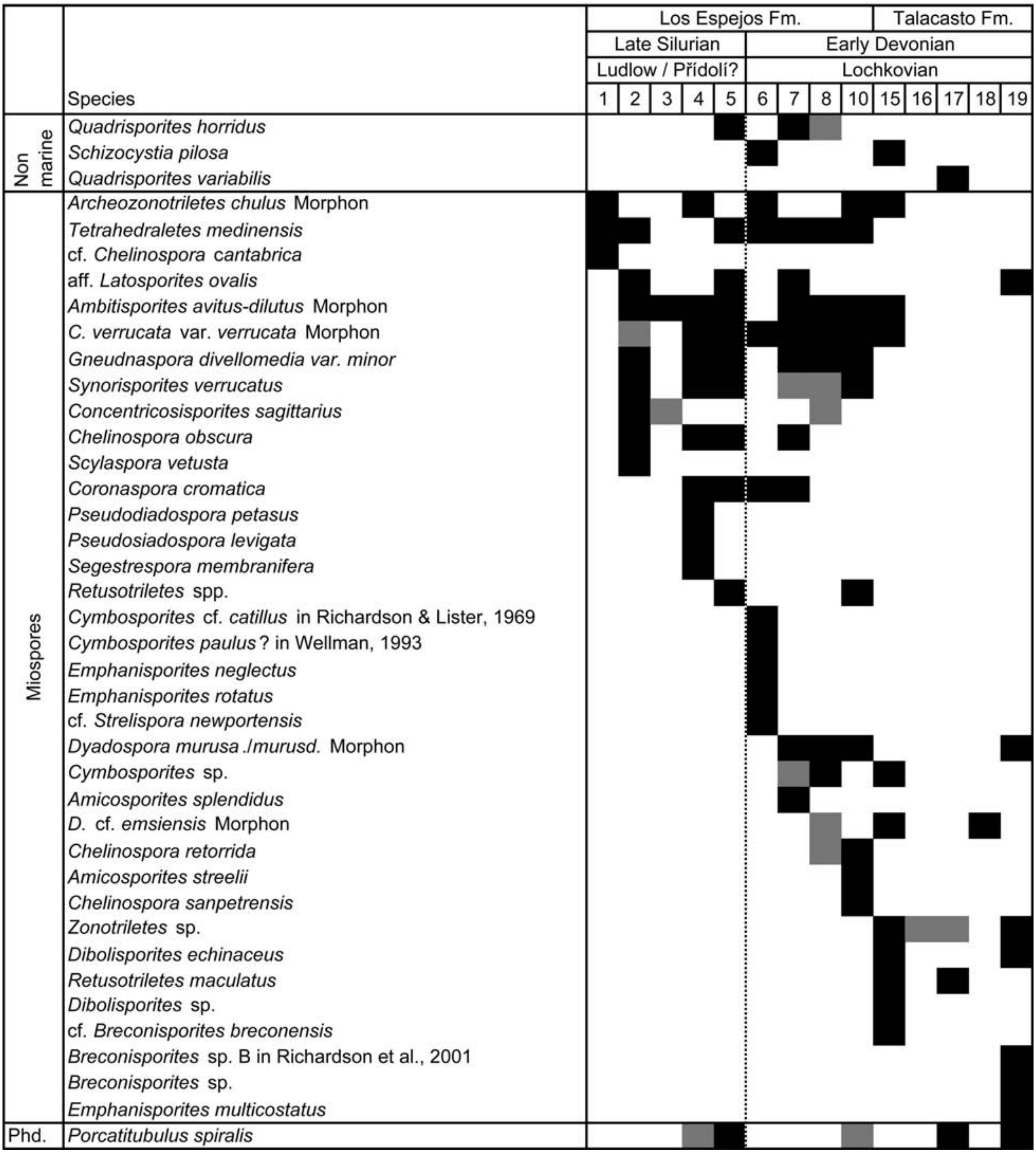

Fig. 4. Stratigraphic distribution of non marine palynomorphs, miospores and phytodebris fragments in the studied section and the proposed ages. Black rectangles mean presence of the species, grey rectangles mean doubtful classification.

kovian time interval, but varying through the basin. The thickness of the Los Espejos Formation decreases from north to south and the younger deposits are only present in the northern outcrops (Sánchez et al. 1995; Astini & Maretto 1996). The diachronism and the gradual shrinking of the formation to the south, render the unit problematic in terms of accurately constraining its age.

The Los Espejos Formation represents siliciclastic shelf deposits, composed mainly of intercalated pelites and sandstones, with evidence of a transgressive to highstand sea-level history (Sánchez et al. 1993; Astini & Maretto 1996). The lower part of the Los Espejos Formation corresponds to a low-energy open shelf deposit followed upwards by storm-dominated shelf and shoreface environments indicated by the increased amount and thickness of the sandstone beds. Astini (1996) identified an uppermost tempestite level, overlaid by a reddish mudstone interval, which has been assigned to the earliest Lochkovian based on the fossil fauna (Benedetto et al. 1992; Sanchez et al. 1995). This reddish mudstone interval has not been observed in the section studied here.

The Talacasto Formation comprises a Lochkovian-upper Emsian marine sequence of greenish-grey mudstone with intercalated sandstone beds (Salas et al. 2013 and references therein). Astini (1991) interpreted the formation as a muddy shelf depositional system developed during highstand conditions. The lower part contains abundant mud concretions related to low-oxygenated shelf environments (Carrera et al. 2013 and references therein). Even though the formation was exhaustively studied (e.g., Amos & Boucot 1963; Baldis 1975; Rustán 2011), it has been most accurately dated as Lochkovian-Emsian based on the brachiopods and terrestrial and marine palynomorphs (Herrera 1991, 1993, 1995; Le Hérisée et al. 1997b).

The tectonic events that took place during the Devonian and, later, during the Andean Orogeny, could be important factors that inhibit the finding of well-preserved palynological assemblages in the Precordillera region (Amenábar 2009).

3. Materials and methods

Ten samples were collected in the upper part of the Los Espejos Formation and nine in the lower part of the Talacasto Formation, in a section located at the southern margin of the Río Jáchal (Fig. 1). From them, 14 have been palynologically productive: nine from the Los Espejos Formation and five from the Talacasto Formation (Fig. 2).

The studied samples were processed in the University of Liège Palynology Laboratory (Belgium), using HCl-HF-HCl acid maceration techniques. The residues were oxidized with a Schulze solution (HNO_3+$KCLO_3$) and screened on a 12 μm sieve.

The palynological slides are housed in the palynological collection of the IANIGLA, CCT CONICET Mendoza, Argentina. Specimens in the slides are located by England Finder coordinates.

4. Palynological results and discussion

In the studied section of the Los Espejos Formation, the palynomorphs were moderately to badly preserved, even though only one level was barren. It should be noted that in previous palynological studies in different sections of the Silurian basin, the upper part of this unit, up to 100 m, was barren (Rubinstein 1993; Le Hérissé et al. 1997b). Therefore, the present study involves the uppermost palynological record of the Los Espejos Formation, which is the closest to the base of the Talacasto Formation considering all the previous studied sections.

Terrestrial palynomorphs, especially trilete spores, constitute approximately 30% of the palynological assemblages in all the studied levels in the Los Espejos Formation. Although the maximum species diversity was shown by the phytoplankton species, with 47 species in total, miospores showed fairly good diversity, with 36 species in total. The highest diversity of phy-

Fig. 5. Palynomorphs on the studied section. Scale bar represents 20 μm. **A** – *Cymatiosphaera* cf. *densisepta* Miller & Eames 1982 in Le Hérissé 2000, slides1-61161 (Q44/3). **B** – *Pterospermella* cf. *circumstriata* (Jardiné et al. 1972) Eisenack et al. 1973, slide 1-61161 (M32/3). **C** – cf. *Nanocyclopia* sp., slide 1-61161 (T21/1). **D** – cf. *Dilatisphaera tubula* Le Hérissé 1989, slide 1-61161 (R22/1). **E** – *Archeozonotriletes chulus* Morphon Steemans et al. 1996, slides 1-61161 (P42/3). **F** – cf. *Chelinospora cantabrica* Richardson et al. 2001, slide 1-61161 (M26/1). **G** – cf. *Tetrahedraletes medinensis* (Strother & Traverse 1979) Wellman & Richardson 1993, slide 1-61161 (Q41/4). **H, Q** – *Ambitisporites avitus-dilutus* Morphon Steemans et al. 1996, slide 2-61160 (G42/2), slide 3-61158 (J24/1). **I** – *Tetrahedraletes medinensis* (Strother & Traverse 1979) Wellman & Richardson 1993, slide 2-61160 (J26/1). **J** – cf. *Concentricosisporites sagittarius* (Rodríguez 1978) Rodriguez 1983, slide 3-61158 (L43). **K** – *Concentricosisporites sagittarius* (Rodríguez 1978) Rodriguez 1983, 2-61160 (Q41/4). **L** – *Scylaspora vetusta* (Rodríguez 1978) Richardson et al. 2001, slide 2-61160 (U35/4). **M** – aff. *Latosporites ovalis* Breuer et al. 2007, slide 2-61160 (E21/4). **N** – *Synorisporites verrucatus* Richardson & Lister 1969, slide 2-61160 (C32/4). **O** – *Evittia* sp. in Rubinstein 1999, slide 3-61158 (K47/1). **P** – Scolecodont, slide 2-61160 (F43/2). **R** – Planar tetrad, slide 3-61158 (M46/4). **S** – *Hispanaediscus wenlockensis* Burgess & Richardson 1991, 3-61158 (N46/2).

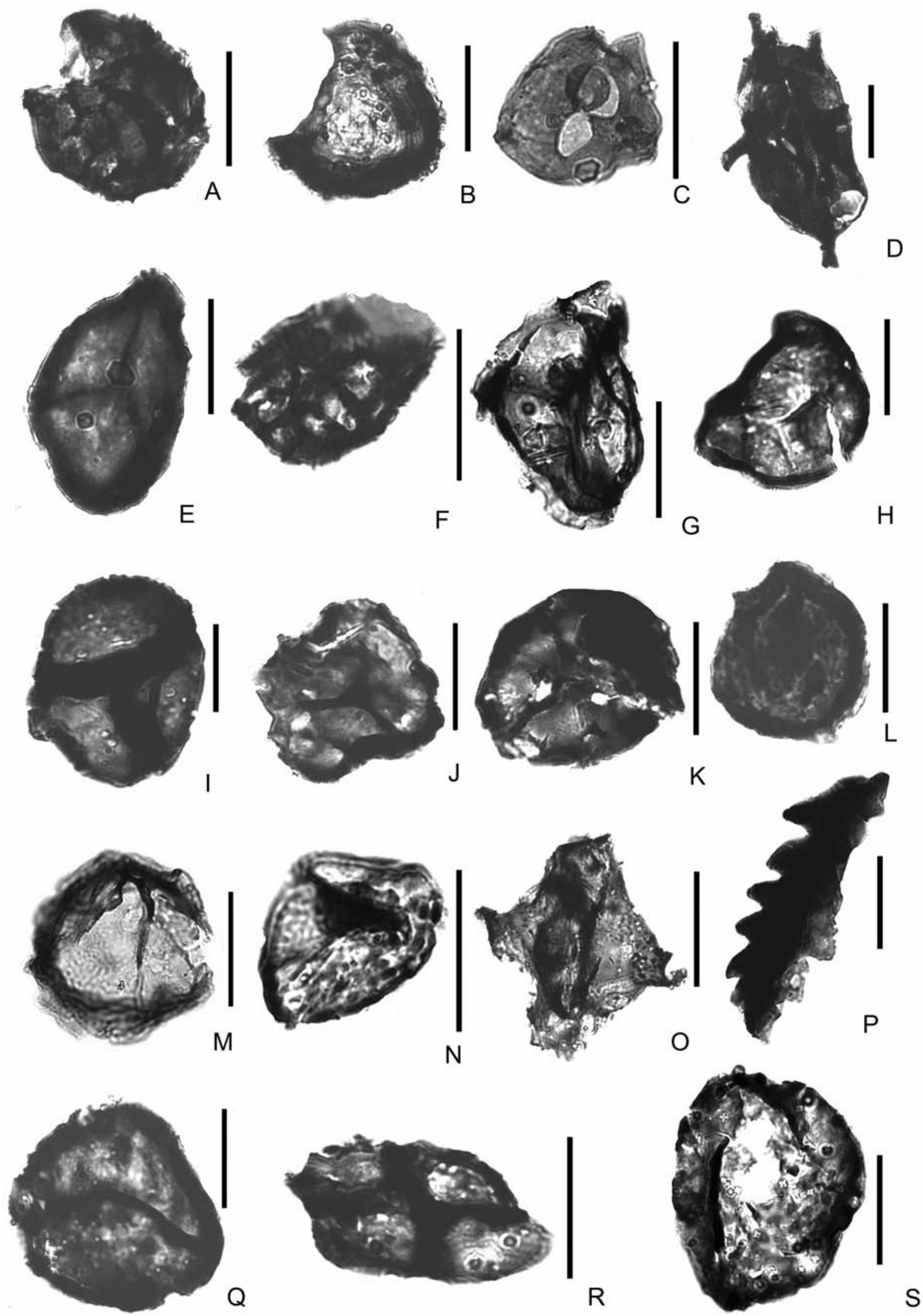

Fig. 5.

Fig. 6. Palynomorphs on the studied section. Scale bar represents 20 μm. **A** – *Helosphaeridium pseudodictyum* Lister 1970, slide 5-61119 (N29/1). **B** – *Duvernaysphaera aranaides* (Cramer 1964) emend. Cramer & Díez 1972, slide 4-61120 (U47/4). **C** – *Polyedryxium* cf. *arcum* Wicander & Loeblich 1977, slide 4-61120 (V34/4). **D** – *Quadraditum fantasticum* Cramer 1964, slides 4-61120 (F27/1). **E** – cf. *Thysanoprobolus polykion* Loeblich & Tappan 1970, slide 4-61120 (H42/2). **F** – *Neoveryhachium carminae* (Cramer 1964) Cramer 1970, slide 5-61119 (Q44/1). **G** – *Chelinospora obscura* Burgess & Richardson 1995, slide 4-61120 (R29/3). **H** – *Coronaspora cromatica* (Rodríguez 1978) Richardson et al. 2001, slide 4-61120 (P41/3). **I** – *Synorisporites verrucatus* Richardson & Lister 1969, 4-61120 (V37/1). **J** – *Stellinium* cf. *rabians* (Cramer 1964) Eisenack et al. 1976, slide 5-61119 (U44). **K** – *Lophosphaeridium* sp., slide 4-61120 (P42/3). **L** – *Pseudodyadospora petasus* Wellman & Richardson 1993, slide 4-61120 (O37/4). **M** – *Pseudodyadospora laevigata* Jonson 1985, slide 4-61120 (L48). **N** – *Segestrespora membranifera* (Johnson 1985) Burgess 1991, slide 4-61120 (K41). **O** – *Tylotopalla* sp., slide 4-61120 (K31/1). **P** – *Cymatiosphaera salopensis* Mullins 2001, slide 8-61116 (G31). **Q** – *Dictyotidium faviforme* Schultz 1967, slide 5-61119 (H36). **R** – *Helios aranaides* Cramer 1964, slide 5-61119 (K41/2). **S** – *Polyedryxium asperum* Cramer 1964, slide 5-61119 (X33/3). **T** – *Comasphaeridium hirtum* Le Hérissé 1989, slide 5-61119 (Q25/1). **U** – *Gorgonisphaeridium*? *listeri* forma A Mullins 2001, slide 5-61119 (Y41/1). **V** – *Micrhystridium* sp., slide 6-61118 (N43/1). **W** – *Porcatitubulus spiralis* Burgess & Edwards 1991, slide 5-61119 (L36/1).

toplankton was observed in level 5-61119, with 17 species. The most diverse spore assemblage was found in level 10-61063, at 0.80 m below the top of the Los Espejos Formation, with 11 species.

In the Talacasto Formation, the lower four stratigraphic levels were barren. In the following five samples, the phytoplankton abundance increases upwards, representing 90% of the assemblage in each level. Although the terrestrial palynomorphs represent almost the same diversity as the phytoplankton assemblages with 13 and 14 species respectively (Fig. 3), the specimens were badly preserved, dark and fragmented.

Next doublepage

Fig. 7. Palynomorphs on the studied section. Scale bar represents 20 μm. **A** – *Synorisporites verrucatus* Richardson & Lister 1969, slide 5-61119 (O32/3). **B** – *Quadrisporites horridus* Hennelly 1959 ex Potonié & Lele 1961, slide 5-61119 (M44/2). **C** – *Multiplicisphaeridium* sp., slide 5-61119 (G48/4). **D** – *Veryhachium trispinosum* Group Servais et al. 2007, slide 5-61119 (W31/1). **E, F, N** – *Evittia* sp. in Rubinstein 1999, slide 5-61119 (R35, F36), 6-61118 (R31). **G** – *Tylotopalla caelamenicutis* Loeblich 1970, 5-61119 (M27/4). **H** – *Tylotopalla deerlijkianum* (Martin 1973) Martin 1978, slide 5-61119 (Q30/4). **I, S** – *Chelinospora verrucata* var. *verrucata* Morphon García Muro et al. 2014, slide 5-61119 (J47/3), 6-61118 (J50). **J** – *Coronaspora cromatica* (Rodríguez 1978) Richardson et al. 2001, slide 5-61119 (Y32). **K** – *Ambitisporites avitus-dilutus* Morphon Steemans et al. 1996, slide 5-61119 (T31/4). **L** – *Chelinospora obscura* Burgess & Richardson 1995, slide 5-61119 (F46/2). **M** – *Dictyotidium dictyotum* (Eisenack 1938) Eisenack 1955, slides 6-61118 (N42/2). **O** – *Schizocystia pilosa* Jardiné et al. 1972, slide 6-61118 (L43). **P** – *Cymbosporites* cf. *catillus* Allen 1965 in Richardson & Lister 1969, slide 6-61118 (F37). **Q, R** – *Cymbosporites paulus*? in Wellman 1993, slides 6-61118 (T41/2); 7-61117-Q47(2). **T** – *Pterospermella* cf. *foveolata* Hill 1974 ex Dorning 1981, slide 7-61117 (N28/1).

Fig. 8. Palynomorphs on the studied section. Scale bar represents 20 μm. **A** – *Emphanisporites neglectus* Vigran 1964, slide 6-61118 (H40/1). **B** – *Emphanisporites rotatus* (McGregor 1961) McGregor 1973, slide 6-61118 (K29/2). **C, D** – cf. *Streelispora newportensis* (Chaloner & Streel 1968) Richardson & Lister 1969, slide 6-61118 (F42/4), two focus. **E** – *Fulgisphaeridium* sp., slide 7-61117 (N36/2). **F** – *Tylotopalla digitifera* Loeblich 1970, slide 7-61117 (P46/3). **G** – *Amicosporites splendidus* Cramer 1967, slide 7-61117 (F37/2). **H** – *Dorsennidium europaeum* (Stockmans & Willière 1960) Sarjeant & Stancliffe 1994 emend. Mullins 2001, slide 8-61116 (R36/4). **I** – *Multiplicisphaeridium rochesterensis* (Cramer & Diez 1972) Eisenack et al. 1973, slide 8-61116 (M46/3). **J** – cf. *Dictyotriletes emsiensis* Morphon Rubinstein et al. 2005, slide 8-61116 (F21). **K** – *Polyedryxium condensum* Deunff 1971, slide 10-61063 (P47/3). **L** – *Amicosporites streelii* Steemans 1989, slide 10-61063 (L39/3). **M-N** – *Chelinospora retorrida* Turnau 1986, slide 10-61063 (Q37/3, V26). **O** – cf. *Concentricosisporites sagittarius* (Rodríguez 1978) Rodriguez 1983, slide 8-61116 (P25/2). **P** – *Chelinospora sanpetrensis* (Rodríguez 1978) Richardson et al. 2001, 10-61063 (K36/1). **Q** – *Synorisporites* verrucatus Richardson & Lister, 1969, slide 10-61063 (U41/3). **R** – *Gneudaspora divellomedia* (Tchibrikova) Balme 1988 var. *minor* Breuer et al. 2007, slide 10-61063 (O43/3). **S** – Scolecodont, slide 10-61063 (G24/3).

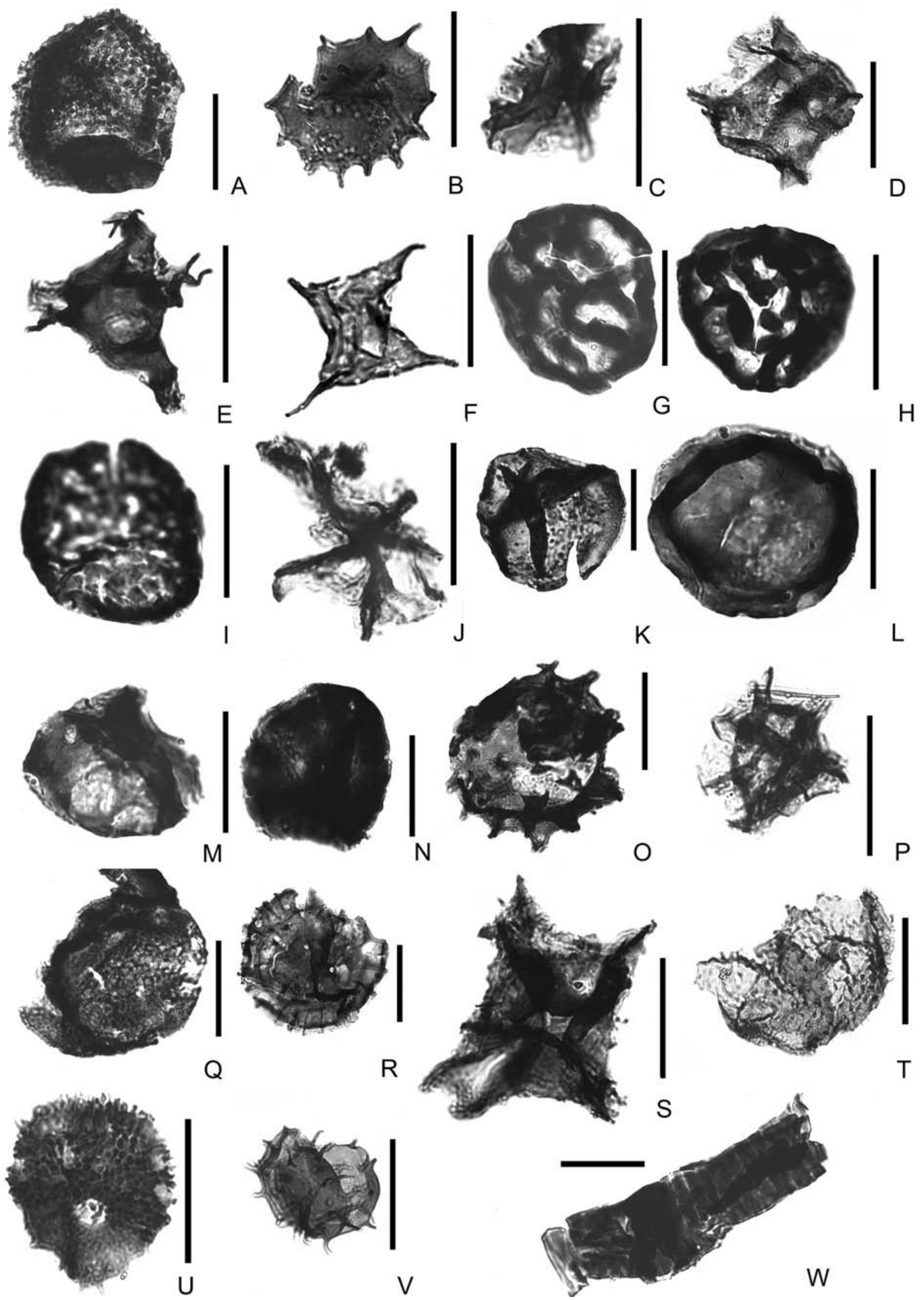

Fig. 6.

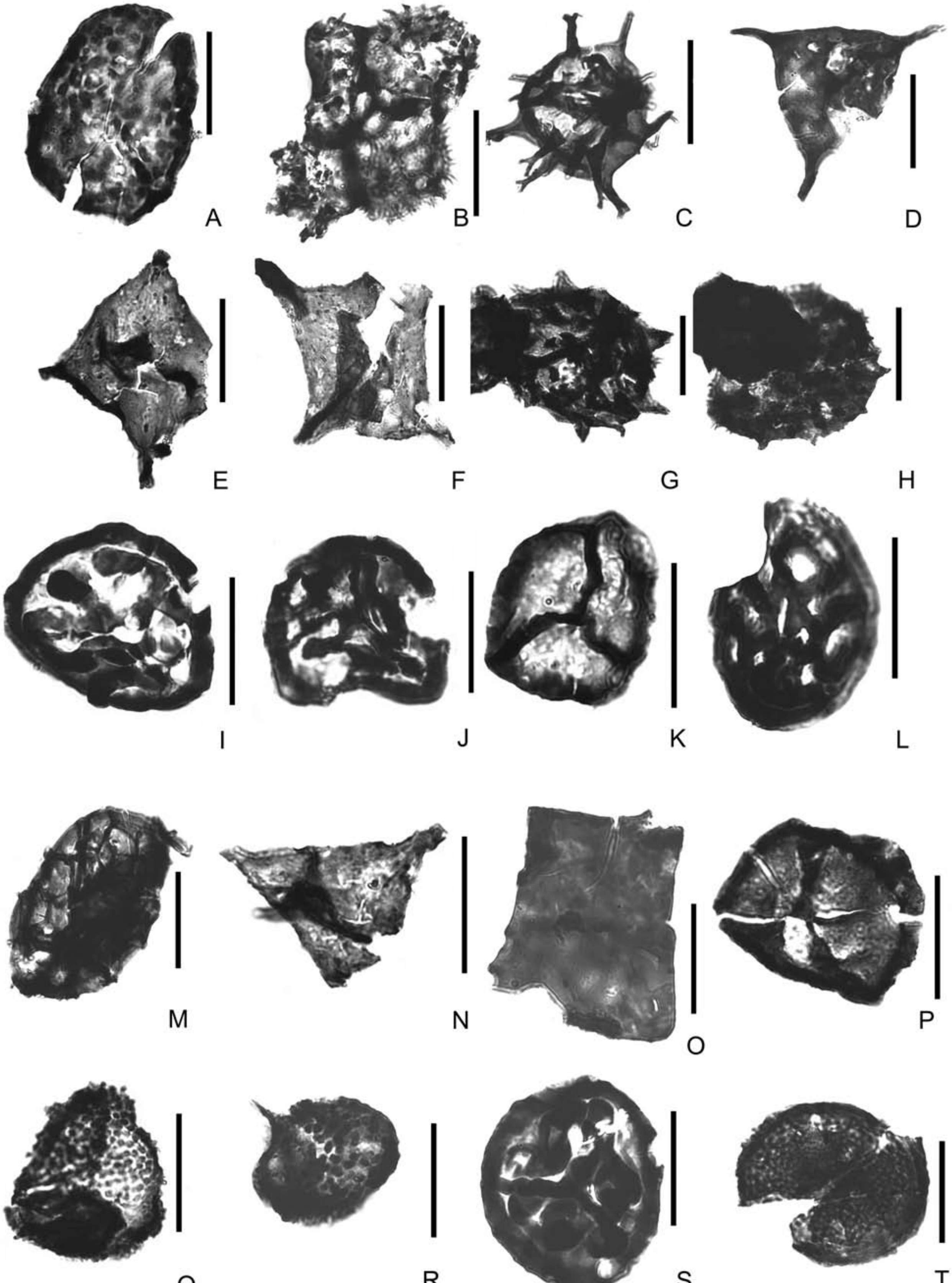

Fig. 7.

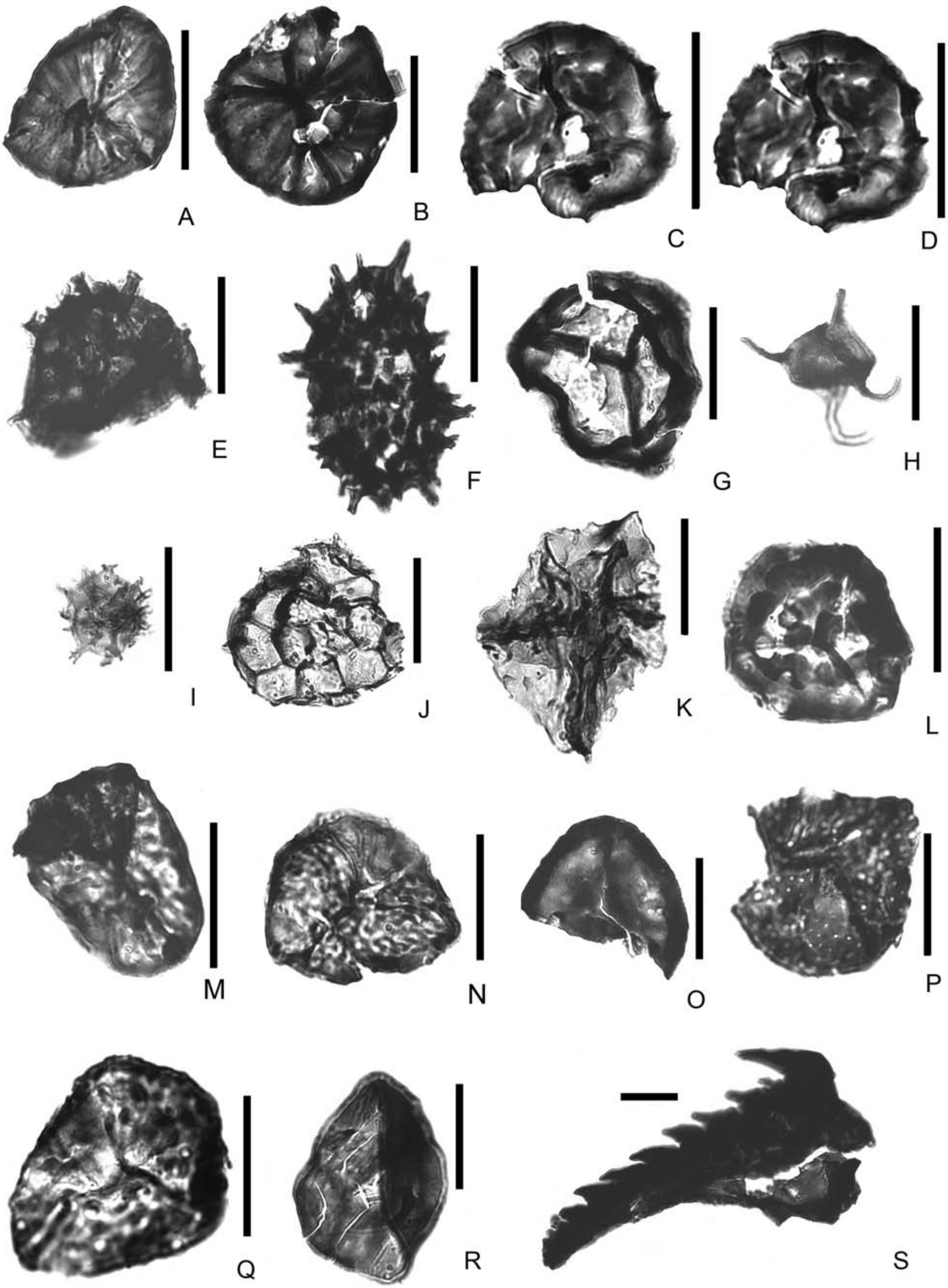

Fig. 8.

The lowest studied level of the Los Espejos Formation, 1-61161 at 25 m below the top of the formation, contains a small number of poorly diversified and badly preserved palynomorphs. Within the phytoplankton, it is possible to distinguish cf. *Dilatisphaera tubula* and cf. *Pterospermella circumstriata* accompanying the spore cf. *Chelinospora cantabrica* (Fig. 5F). It should be noted that *Chelinospora cantabrica* is an accessory species of the *reticulate-sanpetrensis* (RS) and *hemiesferica* (H) biozones of Spain, pointing to a Ludfordian-Přídolí age (Richardson et al. 2001).

The 2-61160 level at 20 m below the top of the Los Espejos Formation, presents a typical Ludlow assemblage with species like *Chelinospora oscura* (Fig. 6G) and Morphon *C. verrucata* var. *verrucata* (Fig. 7I, S).

In level 4-61120 at 10.6 m below the top of the Los Espejos Formation, a specimen of cf. *Thysanoprobolus polykion* was found (Fig. 6E). This is an important biostratigraphic marker for the Lower Devonian; however, the doubtful identification of a single specimen prevents its use for biostratigraphic purposes.

In level 6-61118 at 6.25 m from the top of the Los Espejos Formation, a single specimen of cf. *Streelispora newportensis* was identified (Fig. 8C-D). As mentioned above , the appearance of the *Streelispora newportensis* is an unequivocal indicator of an early Lochkovian age, as part of the MN Zone (e.g., Richardson & McGregor 1986; Richardson et al. 2001; Steemans & Lakova 2004). This species was recorded for the first time in Gondwana, in Tunisia, by Loboziak et al. (1992). The cf. *Streelispora newportensis* recorded in the Río Jáchal locality could represent one of the first records in Gondwana and the first one in South America. Furthermore, its presence could support the recognition of the Silurian/Devonian boundary in the Precordillera of San Juan, confirming the age based on brachiopods.

In addition to the miospore evidence and regarding phytoplankton, a specimen of *Schizocystia pilosa* was found (Fig. 7O). Even though this species was believed to be a biostratigraphic marker for the Lower Devonian, it was also found in Upper Silurian levels in Brazil (Steemans et al. 2008). Moreover, *Schizocystia* is an important palaeogeographic marker since the distribution of the genus is restricted to Gondwana (Jardiné et al. 1972; Le Hérissé et al. 1997b; Rubinstein & Steemans 2007; Rubinstein et al. 2008 and references therein).

In levels 7-61117 and 8-61116, at 4.75 and 2.5 m below the top of the Los Espejos Formation, *Cymbosporites proteus* is present. This species is known from the Lochkovian in Laurussia (McGregor & Camfield 1976; Steemans & Gerrienne 1984) and Gondwana (Rubinstein & Steemans 2002; Rubinstein & Steemans 2007; Rubinstein et al. 2005). In level 8-61116, a specimen of *Dictyotriletes* cf. *emsiensis* Morphon could also support a Lochkovian age for the upper part of the Los Espejos Formation.

The uppermost level of the Los Espejos Formation, 10-61063, at 0.80 m below the top of the Los Espejos Formation, yielded a single specimen of *Polyedryxium condensum* described by Deunff (1971) from the Lower Devonian of Canada and Upper Devonian of the USA. In addition, *Amicosporites streelii* was found in this level (Fig. 8L) with its typical Devonian morphology (Steemans 1989; García Muro et al. 2014).

The four lower levels of the Talacasto Formation were found to be barren while the following higher levels yielded scarce and badly preserved palynomorphs. The interval between levels 15-61186 and 17-61188 at 8-16 m above the base of the unit, contains important biostratigraphic trilete species such as cf. *Dibolisporites echinatus*, cf. *Zonotriletes* sp. and *Retusotriletes tripapillatus*, thus supporting the Early Devonian age for this section.

Concerning the phytoplankton species in level 15-61186, acanthomorphitic dark specimens were abundant, presenting a sub-circular shape and short

Fig. 9. Palynomorphs on the studied section. Scale bar represents 20 µm. **A-C** – *Estiastra culcita* Wicander 1974, slide 15-61186 (K33/2, Q28, V37). **D** – cf. *Breconisporites breconensis* Richardson et al. 1982, slide 15-61186 (W41). **E** – *Zonotriletes* sp., slide 15-61186 (L28). **F** – *Crasiangulina tesselita* Jardiné et al. 1972 emend. Wauthoz et al. 2003, slide15-61186 (U35/3). **G** – *Cymbosphaeridium* sp., slide 15-61186 (J39/3). **H** – *Dibolisporites* sp, slide 15-61186 (M32). **I** – *Cymatiosphaera acuminata* Mullins 2001, slide 15-61186 (V28/2). **J, P** – *Cymbosporites* sp., slides 15-61186 (O37/3); 18-61189 (R36/4). **K, Q** – *Dictyotriletes emsiensis* Morphon Rubinstein et al. 2005, slides 15-61186 (Q47/3-4); 18-61189 (F26/4). **L** – *Retusotriletes maculatus* Mc Gregor & Camfield 1976, slide 15-61186 (J35/3); 17-61188 (N45/3). **M** – *Leiofusa* sp., slide 16-61187 (D44/3). **N** – *Quadrisporites variabilis* (Cramer 1966) Ottone 1996, slide 17-61188 (N45/3). **O** – *Porcatitubulus spiralis* Burgess & Edwards 1991, slide 17-61188 (Q27). **R** – *Gorgonisphaeridium* sp., slide 18-61189 (T22/3). **S** – *Multiplicisphaeridium* sp., slide 18-61189 (J30/3). **T** – *Breconisporites* sp. B in Richardson et al. 2001, slide 19-61191 (F39).

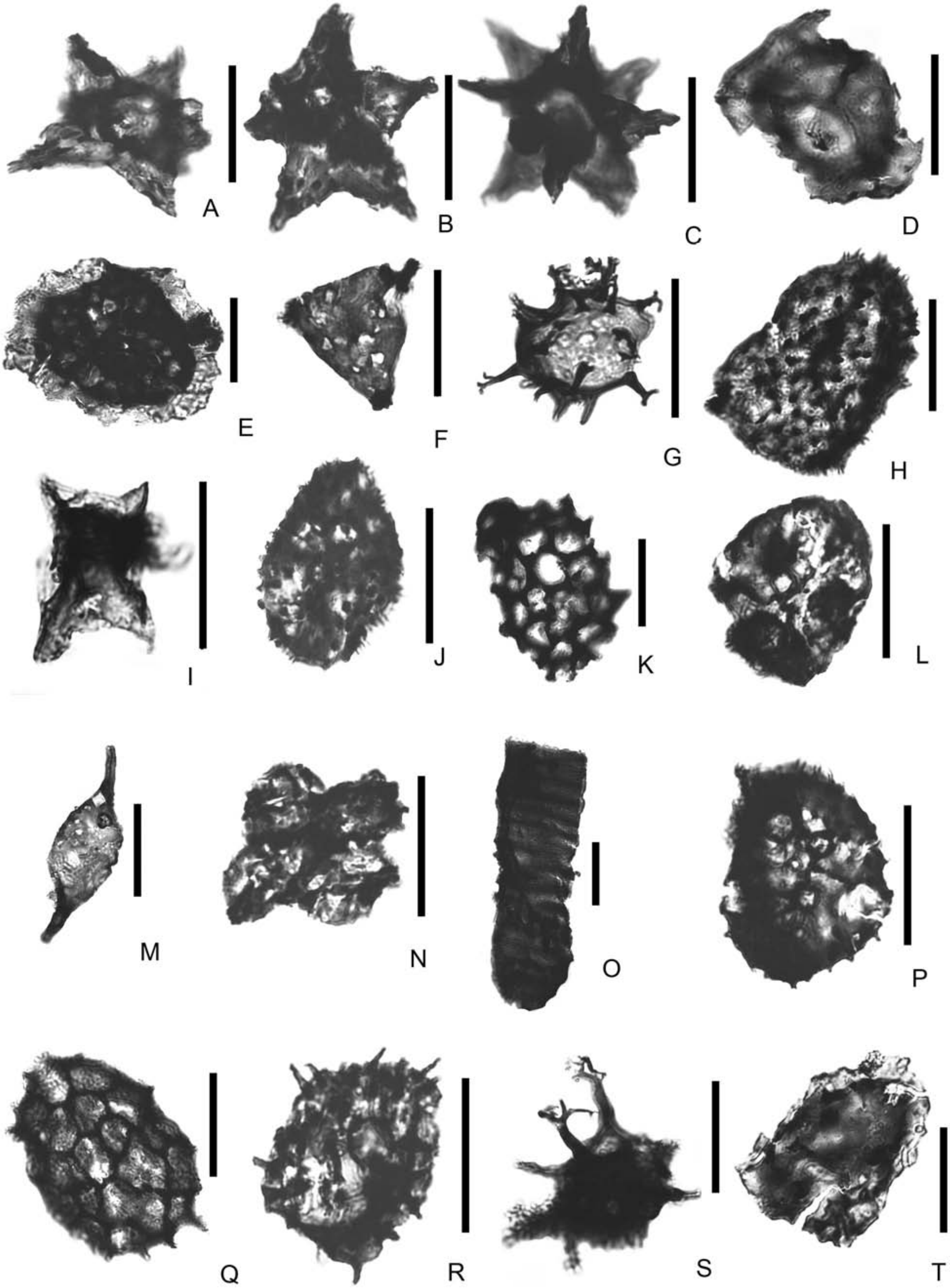

Fig. 9.

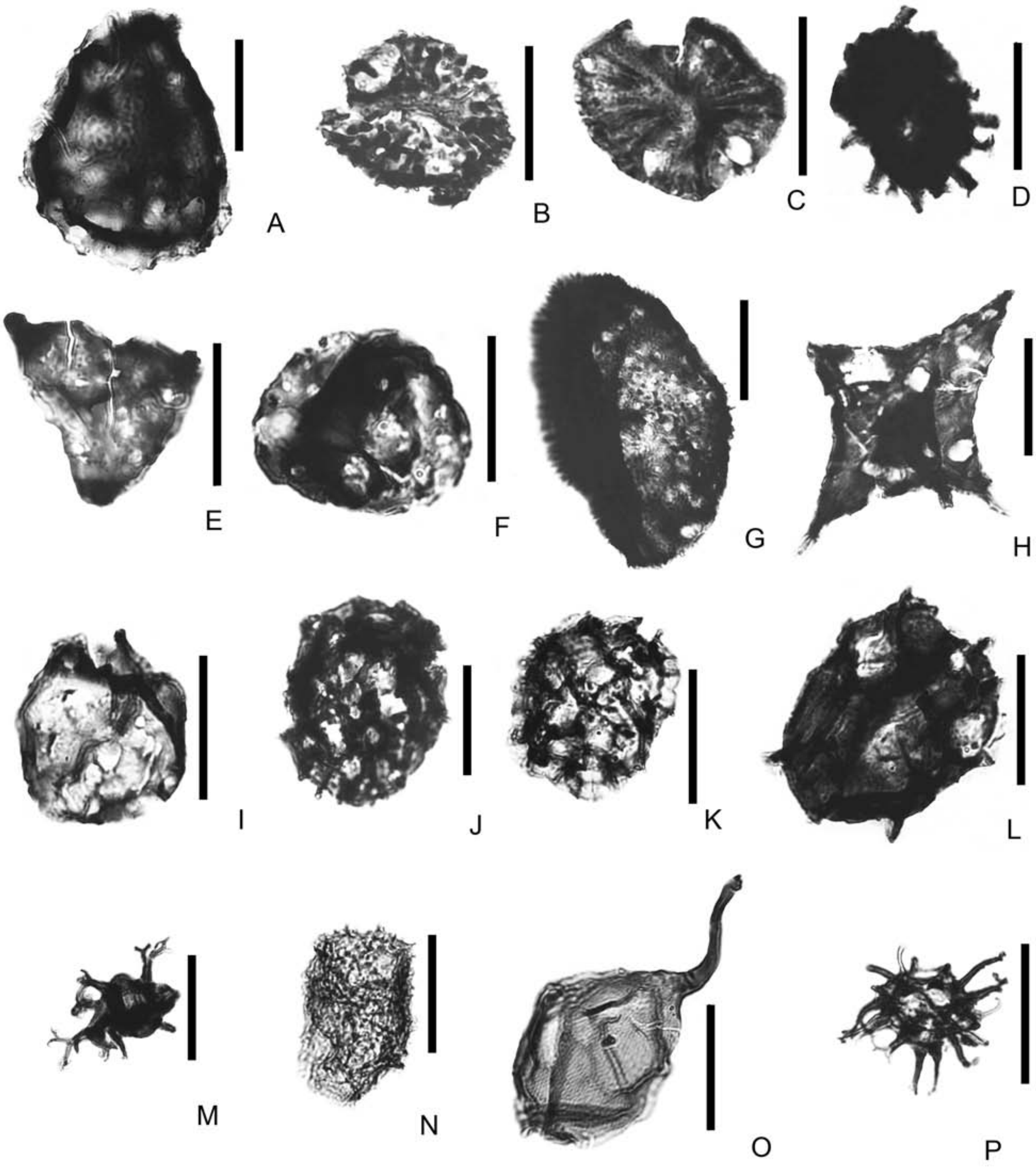

Fig. 10. Palynomorphs on the studied section. Scale bar represents 20 μm. *Breconisporites* sp., slide 19-61190 (U39/4). **C** – *Emphanisporites multicostatus* RODRIGUEZ, 1978, slides 19-61190 (G32/3), 19-61191 (D34/1). **D** – cf. *Dilatisphaera tubula* LE HÉRISSÉ 1989, slide 19-61191 (N35/3). *Crassiangulina teselita* JARDINÉ et al. 1972 emend. WAUTHOZ et al. 2003, slide 19-61191 (F48/1). *Dyadospora murusdensa murusatenuata* Morphon STEEMANS et al. 1996, slide 19-61191 (U49/3). *Dibolisporites echinaceus* (EISENACK) RICHARDSON 1975, slide 19-61191(E41). *Estiastra culcita* WICANDER 1974, slide 19-61191 (O47/2). **I** – aff. *Latosporites ovalis* BREUER et al. 2007, slide 19-61191 (G24/4). *Dictyotidium perlucidum* LE HÉRISSÉ 1989, slide 5-61119 (S49/2). *Cymatiosphaera* aff. *multisepta* DEUNFF 1955 in MULLINS 2001, slide 10-61063 (U36/3). *Cymatiosphaera* cf. *nimia* LE HÉRISSÉ 2002, slide 7-61117 (J25). *Multiplicisphaeridium arbusculiferum* (DOWNIE 1963) LISTER 1970, slide 8-61116 (O37). *Helosphaeridium clavispinulosum* LISTER 1970, slide 10-61063 (F23). *Eupoikilofusa tenuistriata* (PÖTHE DE BALDIS 1975) PÖTHE DE BALDIS 1981 emend. MULLINS 2001, slide 10-61063 (N23/4). *Multiplicisphaeridium variabile* (LISTER 1970) DORNING 1981, slide 10-61063 (U24/2).

cylindrical to columnar processes which may have denticulate branches. Such characteristics make them similar to the genus *Multiplicisphaeridium*. Several specimens of *Estiatra culcita*, which had been previously identified in the Upper Devonian of the USA (Wicander 1974; Wicander & Playford 2013), were also recorded. In the studied level, *Estiatra culcita* represents more than 16% of the phytoplankton. Because of this restricted occurrence, it cannot be used as a biostratigraphic marker, but its high abundance probably represents an opportunistic behaviour of this species in a changing environment (Troth et al. 2010).

Samples 16-61187 to 18-61189 do not display biostratigraphically relevant taxa. Some specimens of *Dictyotriletes* cf. *emsiensis* Morphon are present, thus still supporting an Early Devonian age.

The uppermost studied level, 19-61190, contains *Emphanisporites multicostatus* (Fig. 10B, C), a species that ranges from the Přídolí to the Pragian (Rodriguez 1978a; Gourvennec et al. 2010; Steemans et al. 2008), and zonate pores such as *Breconisporites* sp.; indicating that the Early Devonian age sediments possibly extend at least to 31.5 m above the base of the Talacasto Formation.

Consequently, the whole palynological record of the studied section would point out to a Late Silurian (Ludlow/ Přídolí?) - Lochkovian age. In addition, it is possible to identify the Silurian/Devonian boundary within the Los Espejos Formation.

4. Conclusions

The Silurian/Devonian boundary based on organic-walled phytoplankton has been very difficult to recognize worldwide because of their scarcity and the lack of species with stratigraphic and correlatory value. Whereas, by contrast the terrestrial palynomorphs, mainly the trilete spores, have been demonstrated to be useful for age constraint of this system boundary. The terrestrial and marine palynological assemblages of the studied Río Jáchal section indicate a Ludlow/ Přídolí? to Lochkovian age. This permits the recognition of the possible position of the Silurian/Devonian boundary in the San Juan Precordillera, Argentina; which is in concordance with the brachiopod dating (Benedetto 1992). Several important biostratigraphic species such as one possible *Streelispora newportensis*, have been recorded. The presence of a diversified miospore assemblage, in addition to the sedimentary record, suggests proximity to the coast line.

Even though a stratigraphic gap was proposed spanning the boundary between the Los Espejos and the Talacasto formations (Rustán & Vaccari 2010 and references therein), it was not possible to identify it because the palynological assemblages inhibit more high-resolution dating. The Lochkovian age interpreted for the lower part of the Talacasto Formation in the Río Jáchal section, corresponds with the age of the basal part of this unit at Cerro del Fuerte section.

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